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THE ORIGIN OF DAEMONELIX

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ABSTRACT

Attention is called to the controversy of some years ago over the origin of the "Devil's Corkscrews." The problem may have appeared unimportant then, but now a correct understanding of the paleoecology of Harrison time may hinge on the explanation of these strange "fossils." The characteristics of Daemonelix are briefly reviewed, they are compared to the lianas of the modern tropical jungle, and the postulated conditions of Harrison sedimentation are believed to supply an adequate explanation for the presence of fossil rodent remains in the Daemonelices. The possibility of a vegetal origin of these fossils is believed to be demonstrated.

INTRODUCTION

From twenty-five to thirty-five years ago a controversy regarding the origin of Daemonelix[1] was carried on with some vigor without arriving at any definite conclusions. The matter was dropped; perhaps the origin of Daemonelix did not seem important. But now it appears that this problem may be important, because the origin of these remarkable structures in the upper part of the Harrison formation seems to be related closely to the climatic and sedimentation conditions which prevailed during late Harrison time. A correct

[1] The original spelling of this word by E. H. Barbour (1892) was "Daimonelix," which he altered a little later to the familiar "Daemonelix," as used herein. The latter spelling has come into such general and accepted use that it is believed unwise to revert to the original form. Since the word is no longer regarded as a proper generic term, as later indicated in this paper, it will not be italicized.

understanding of the paleoecology of that time may hinge on the origin of the Daemonelix.

The Harrison formation is the uppermost of three formations (Gering, Monroe Creek, and Harrison) which make up the Arikaree group within the Miocene series in Nebraska. The Harrison formation formerly was known as the "Lower" Harrison, but it has been redefined[2] and is now understood in the sense in which it was originally defined by J. B. Hatcher.[3] The age of the Harrison is regarded by the writer as late Middle Miocene.[4] The "Daemonelix beds" form the upper part of the formation, averaging about 100 feet in thickness and occurring mainly in central and northern Sioux County, Nebraska.

DAEMONELIX STRUCTURES

The Daemonelix or "Devil's Corkscrews," first described by E. H. Barbour in *Science*, February 19, 1892, are apparently restricted to the upper half of the Harrison formation. They are composed mainly of hard, cemented sand and silt which have somehow replaced an original vegetal structure or filled a rodent burrow having this most unusual form, according to whichever theory of origin the reader prefers. Fossilized plant cells and microscopic vegetal structures, mainly silicified, have been observed in the Daemonelix. Rodent skeletons have been found completely enclosed in them. Considerable quantities of colloidal silica have been observed filling tubes and canals and occupying interstitial space within the structures. Barbour states: "The walls of these stems, which are thick and fairly solid and a chalk-white color, encircle a core of sandstone, perforated more or less by ramifying tubes and tubules."[5]

The individual "stem" of the true Daemonelix ranges from 2 or 3 inches in diameter up to 8 or 10 inches in the larger specimens. The

[2] A. L. Lugn, "The Nebraska State Geological Survey and the Valentine Problem," *Amer. Jour. Sci.*, Vol. XXXVI (1938), pp. 220–27; also "Classification of the Tertiary System in Nebraska," *Bull. Geol. Soc. Amer.*, Vol. L (1939), pp. 1245–76.

[3] "Origin of the Oligocene and Miocene Deposits of the Great Plains," *Proc. Amer. Phil. Soc.*, Vol. XLI (1902), pp. 113–31.

[4] Lugn, "Classification of the Tertiary . . . . ," *op. cit.*

[5] "On a New Order of Gigantic Fossils," *Univ. Nebraska Studies*, Vol. I, No. 4 (1892), pp. 301–35.

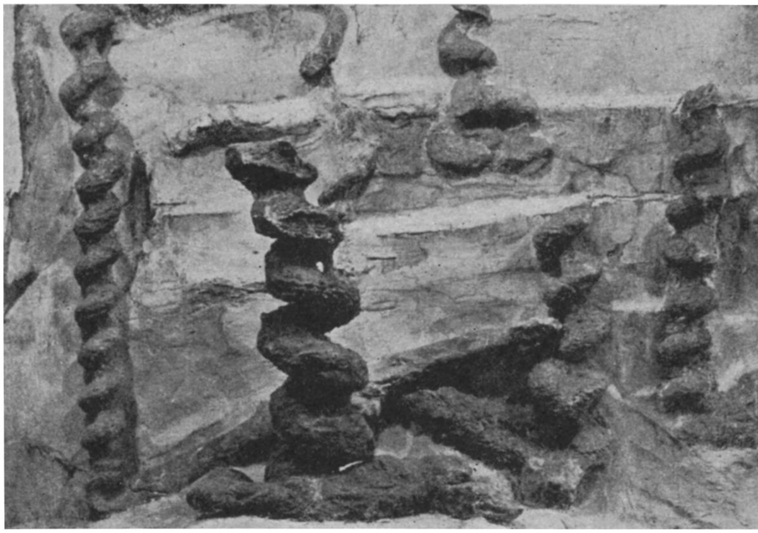

FIG. 1.—Typical Daemonelix structures. Nebraska State Museum, Lincoln Nebraska. Photo by A. L. Lugn.

FIG. 2.—Typical Daemonelix structures. Nebraska State Museum, Lincoln, Nebraska. Photo by A. L. Lugn.

stems are spirally coiled upward, the whorls turning either to the right or to the left, there seeming to be about an equal number spiraled each way. The diameter of the whorls or of the entire gross

FIG. 3.—Peculiar wide-coiled Daemonelix structure with several broken branches around the uppermost whorl and one branch visible lower down; a rhizome structure extends to the upper right from the lower end of the coil. Nebraska State Museum. Photo by A. L. Lugn.

structure ranges from about 8 inches or less to 3 feet or more, and the whorls generally expand upward. They stand in a vertical position when undisturbed and their height of 6 or 8 feet probably represents but a part of the original height of the corkscrew. Many of the Daemonelix are coiled about a definite, slender, vertical axis; but others are open coils without apparent axes. Possibly the uniformity of the encoiled axial space indicates the former existence of some structure less preservable than the corkscrew itself. The ac-

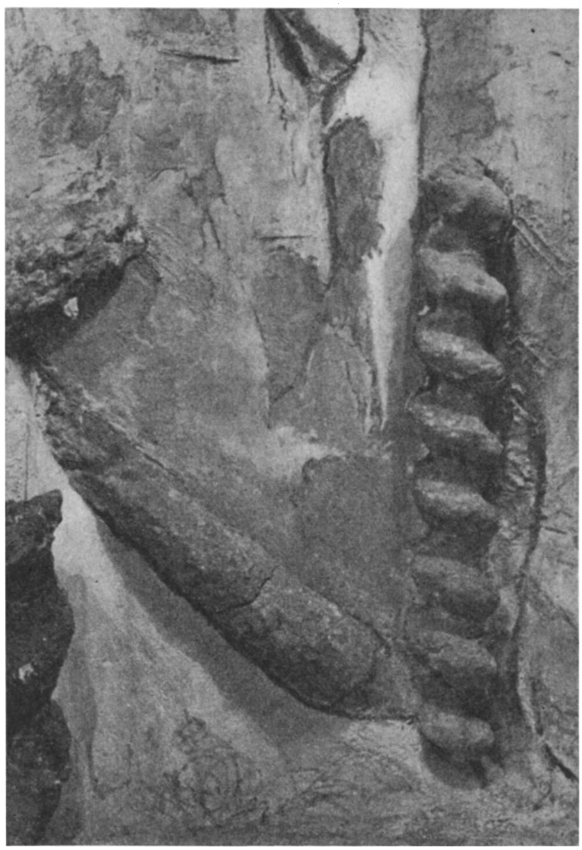

FIG. 4.—A typical slender Daemonelix coiled about an axis with a heavy rhizome structure leading down to the base from the upper left. Nebraska State Museum. Photo by A. L. Lugn.

companying photographs (Figs. 1, 2, 3, and 4) illustrate the appearance of these strange structures better than words can depict.

Many of the markings on excavated specimens of Daemonelix, now on display in the Nebraska State Museum, which may resemble rodent claw marks, especially in some photographic illustrations, may be only tool and brush marks made in cleaning the corkscrews. Some of them, collected in 1891, have been much handled, set up for display several times, and cleaned on several occasions during the last fifty years. Real rodent claw marks also may be present, as will be suggested in the explanation which follows later.

Barbour stated:

> As to numbers and distribution, the fossil corkscrews are scattered pretty evenly throughout these beds, and wherever fully exposed, it is plain they flourished in thickly crowded forests of vast extent. In one case six grew almost in contact; in another, ten were counted in a space eight yards long by two yards wide. Along the well-washed banks of a small draw, in a space about two hundred by thirty feet, some forty large specimens were counted and ten dug out.[6]

Barbour considered a number of possible modes of origin for these structures. He thought it "entirely untenable" that they could have been formed by mechanical means, by burrowing animals, or by geysers or springs. "Neither are they accidents, mere freaks, or concretions." He gave favorable consideration for a time to the idea that they might be sponges, but it is quite clear in all his papers that he favored from the first the idea that they had a vegetal origin.

Barbour came to be strongly convinced that

> all forms are constant in that they are made up of a tangle, or aggregate, or colony of plant filaments, which in section show an identical structure . . . . , simply an aggregation of individual plant fibres twisting to the right or to the left without reference to any discoverable law.[7]

He did not think that "the whole fossil is one plant with bark, sapwood, and heart-wood, such as one finds in a modern vine coiled about some axis." However, the preservation of structural minutiae is so poor that this point can hardly be definitely determined, and it is the view of the writer that many, if not most, of the Daemonelix structures were organized higher plants similar to the modern lianas of the tropical jungles.

[6] *Ibid.*, p. 10.

[7] "History of the Discovery and Report of Progress in the Study of Daemonelix," *Univ. Nebraska Studies*, Vol. II, No. 2 (1897), pp. 81–124.

Barbour also states:

> The tubules and tubes of Daemonelix . . . . are perfectly distinct as white, hollow tubules, scarcely a millimeter in diameter, branching and tangled together like a bunch of tow. They constitute the visible part of all forms of the Daemonelix group. Each filamentary tubule is looked upon as the plant proper, while their aggregation into a particular form constitutes the several varieties described herein. . . . .
>
> Microscopic sections from these tubes reveal a cellular structure so unmistakable, so defined and clean cut, as to be equalled only by a section from a living plant. . . . .[8]

In summing up, Barbour later says of the Daemonelix structures: "This much is known: that they are vegetable; that they are cellular, and not vascular; that the body of the rhizome is occupied by them . . . . ." Thus it would appear that Barbour visualized the Daemonelix made up of innumerable thin filaments and tiny stems growing together in great aggregate, ropy spirals, and not as single, highly organized plants or vines as we know them. His conception is understandable when it is remembered that Barbour believed that Harrison sedimentation took place in a large body of water, such as a fresh-water lake, and not subaerially as we now understand it to have occurred. That the filaments or "tubules and tubes" were "cellular, and not vascular" is strongly contradicted by the figures and illustrations published by Barbour himself. Several of these illustrations show open tubes surrounded by cells, definitely organized, it is true; but it is the writer's belief that these structures represent parts of distinct vascular bundles from some well-organized higher plant, which have resisted decomposition.

Much of Barbour's description of these structures is indefinite and in some respects contradictory; and one thing stands out quite clearly in all his papers on the subject, namely, that he, himself, had not formed a very definite idea of the exact nature of these strange "fossils." This militated against his explanation of their origin and left him more open to attack by the proponents of the burrow theory than would have been the case had he been able to make full and advantageous use of all the favorable evidence on his side of the question.

[8] *Ibid.*

Nevertheless, Barbour[9] proposed to trace the phylogeny of Daemonelix; and he suggested that, since the smallest stem and rootlet fossilization—the "Daemonelix fibres"—occur low in the zone and these seem to be succeeded by "Daemonelix cakes," "Daemonelix balls," "Daemonelix cigars," "Daemonelix Irregular," "Daemonelix Regular," and "Daemonelix layers" in order to the top of the formation, this represented an evolution of a group of organisms for which he had earlier proposed the family name "Daimonelicidae" and assigned all forms to the genus *Daimonelix* (later changed to *Daemonelix*).[10] It is true that the most perfectly formed, typical, large structures occur in the upper part of the Daemonelix beds of the Harrison formation; but that irregular forms and fibers, the stems and rootlets, the vegetal masses, etc.—are absent except in the lower beds is incorrect. They also occur more or less throughout the formation. It seems most likely that many of these irregular forms had no kinship whatsoever with the true Daemonelix and that many different kinds of vegetation have been erroneously catalogued as Daemonelix. Also, it seems not unlikely that some of the more irregular forms like the "cakes" and "balls" represent simply the fossilized dung of large mammals which undoubtedly roamed over the terrain during the drier times when the corkscrews were being buried, as will be noted later.

N. H. Darton[11] accepted the plant theory but offered no evidence in favor of it or in opposition to any other theory. He simply stated: "It is believed that no one observing these fossils in the field would have any doubt as to their vegetal nature." This kind of statement is fairly typical of this controversy, which has been characterized by rather positive statements, convincing enough to their authors but not impressive to the unbiased reader.

O. A. Peterson[12] held to the burrow theory to explain the origin of these strange forms. He reported finding at one place six rodent

[9] "History of the Discovery . . . . ," *op. cit.*

[10] "On a New Order . . . . ," *op. cit.*

[11] "Geology and Water Resources of Nebraska West of the One Hundred and Third Meridian," *U.S. Geol. Surv. Prof. Paper 17* (1903), pp. 69.

[12] "Recent Observations upon Daemonelix," *Science*, Vol. XX (new ser., 1904), pp. 344–45.

skeletons inside of Daemonelix structures in one day and others at other locations at other times. In one case he states that a skeleton was found in the rhizome of the Daemonelix with the head toward the "exit"—the spiral part of the structure—"when it was overtaken by some accident and died." It seems evident from Peterson's papers on the subject that the finding of fossil rodent bones inside these structures *ipso facto* established in his mind proof of the burrow theory of their origin, although he recognized that plant remains had also been found within them. He[13] gave much weight to the fact that the fossil rodent remains found in these structures "are of the proper size in comparison with the average size of Daemonelix." This might be expected in any circumstance, since no rodent will willingly squeeze himself into an undersized burrow, nor does any burrowing animal choose to live in oversized living quarters—a trait acquired through generations of economical burrowing habits. Peterson also notes that the small, irregular, so-called "Daemonelix" "cannot properly be classified with the typical Daemonelix." This, no doubt, is a correct observation, but it and also the size of the rodent remains have no important bearing on the question of whether the "typical Daemonelix" are rodent burrows or have some other origin.

C. B. Schultz[14] is in agreement with the view that all Barbour's Daemonelices are not correctly classified as such; and he indicates strong conviction that many of these forms are vegetal and that the term should be applied only to the "large coiled forms," which he is inclined to regard as rodent burrows—and such they might well have been sometime during their history, as will be indicated.

E. S. Riggs,[15] in an abstract of a paper presented before the American Society of Vertebrate Paleontologists, concluded that at some stage of their formation these spirals had been open holes, although

[13] "Description of New Rodents and Discussion of the Origin of Daemonelix," *Carnegie Mus. Mem.*, Vol. II (1905), pp. 139–202.

[14] "Oreodonts from the Marsland and Sheep Creek Formations, with Notes on the Miocene Stratigraphy of Nebraska" (unpublished thesis, University of Nebraska Library, 1941).

[15] "Loup Fork Beds of Eastern Wyoming (abstr. rep.), *Science*, Vol. XXIX, No. 735 (new ser., 1909), p. 196.

their mode of origin was still obscure. He also stated: "In connection with a possible vegetable origin, attention was drawn to the spirally coiled lianas common in tropical forests. These, if buried in sand, might decay and leave an open hole." It seems most unfortunate that this significant lead did not at that time result in a more adequate and correct understanding of these odd fossils.

H. E. and A. E. Wood[16] have reviewed the Daemonelix problem in some detail. It is apparent, however, that they gave little credence to a vegetal origin and strongly favored the burrow theory. They state: " . . . . It is fairly certain that the burrow hypothesis is the more widely accepted one." This is easily understood since it seems apparent to the writer that the structures which they described and illustrated from Rock Creek Draw in Briscoe County, Texas, quite certainly are true rodent burrows, in no way comparable to the Harrison Daemonelices of Nebraska.

The writer has encountered fossil rodent burrows of many kinds filled with silty clay or volcanic ash in the Pleistocene formations (sands and gravels) of Nebraska and other regions and in the Ogallala beds. Such fossilized rodent burrows, filled with somewhat indurated volcanic ash, in the Ogallala ("Loup Fork") of Sheridan County, Nebraska, are illustrated in Figures 5 and 6. The writer has experienced no difficulty in distinguishing fossil rodent burrows of this kind from the true Daemonelix found only in the upper part of the Harrison formation. He has felt no inclination to attempt to classify the two kinds of structures together. They are so evidently different that one thoroughly familiar with both in the field will not even fancy that they might have had a common mode of origin. Furthermore, all the burrow forms of Daemonelix reported by anyone or seen by the writer are of the irregular type, and most of them do not even closely resemble the true Harrison Daemonelix. Only the rodent burrow reported and illustrated by Schultz[17] closely resembles the true Harrison form. He presents some new but inconclusive evidence "pointing to the rodent-burrow origin of the Daimonelix."

[16] "Daemonhelix in the Pleistocene of Texas," *Jour. Geol.*, Vol. XLI (1933), pp. 824–33.

[17] *Op. cit.*

FIG. 5.—Some typical "fossilized" rodent burrows in the Ogallala beds of Sheridan County, Nebraska. These burrows extend downward from the contact at the base of the bed of volcanic ash across the top of the picture. They are filled with slightly hardened ash. Photo by A. L. Lugn.

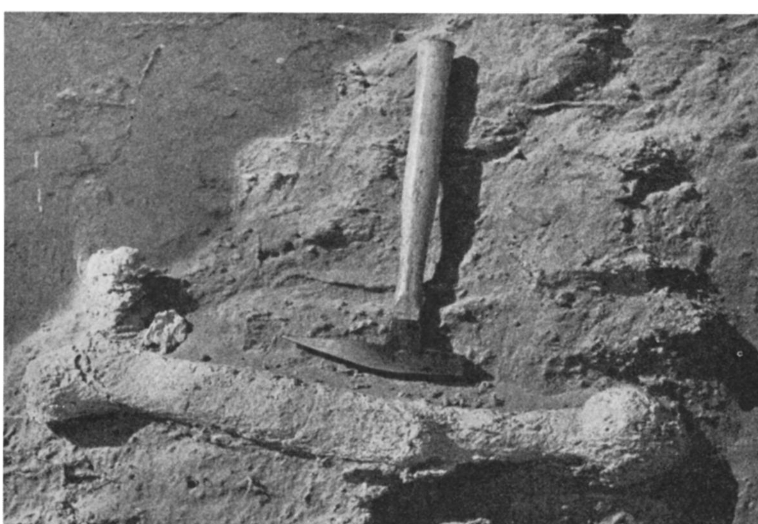

FIG. 6.—Fossilized rodent burrow in the Ogallala beds of Sheridan County, Nebraska; observed near those pictured in Fig. 5, also filled with volcanic ash. Photo by A. L. Lugn.

ORIGIN OF DAEMONELIX

Thus far little effort has been made to harmonize the two opposing theories of the origin of Daemonelix. The proponents of the burrow and the plant theories have each been fully satisfied with their own evidence and conclusions and have been satisfied to meet the arguments of the other group with more or less categorical denials. Any satisfactory theory to explain the Daemonelix must account for the very impressive plant and vine resemblances of these structures, the perfectly fossilized plant cells and other minute structures preserved in them, and also for the rodent remains found in so many of them.

BEAVERS

One genus of beaver, *Paleocastor*—the Harrison beaver—is associated with the Daemonelix beds. However, Barbour[18] pointed out that bones of other animals, which could in no way be considered responsible for the Daemonelix structures, had been found in them or more or less enclosed by them, as if the vegetal growth had encroached on and surrounded the skeletal parts during or after burial.

By those who adhere to the burrow theory beavers are now held primarily responsible for the Daemonelix structures. Beavers in Nebraska are known at least from Brule (Oligocene) time to the present, and yet only during the later part of Harrison time do they appear to have made and occupied, if actually they did, these unusual "Daemonelix" burrows. There are no known true Daemonelix structures in the Pliocene, Pleistocene, or Recent deposits. The fact that a single modern rodent burrow has been found that somewhat closely resembled Daemonelix when filled with plaster and the plaster then excavated may represent only an erraticism. Peterson[19] also made much of the form of two modern prairie-dog burrows which his party filled with plaster and then excavated. The two casts which he illustrates appear to the writer to lack any resemblance to true Daemonelix structures.

The fact that Daemonelix is restricted to a limited stratigraphic range within only a part of a single geologic formation seems to the writer strong evidence against the burrow theory. If the beavers

[18] "History of the Discovery . . . . ," *op. cit.*

[19] "Description of New Rodents . . . . ," *op. cit.*, pp. 188–89.

rather suddenly acquired the habit of constructing Daemonelix burrows, which are plentiful and occur only in the upper part of the Harrison formation, it seems odd indeed that, since beavers continued to thrive through later ages, they should have lost or abandoned suddenly the habit of constructing Daemonelix burrows at a geological contact—the top of the Harrison formation. On the other hand, the disappearance of a specific and unusual plant form would not be at all strange with the advent of changed environmental conditions.

LIANAS

M. K. Elias, while viewing the Daemonelix display in the Nebraska State Museum, remarked to the writer on the very close similarity of these structures to the lianas of the Colombian jungles of South America. He had been impressed by the size and climbing characteristics of these huge vines while engaged in oil-geology exploration in Colombia a few months before seeing the Daemonelix display. He commented to the effect that the lianas were almost exact duplicates of the Daemonelix in size and range of size, in being coiled right-handed or left-handed, in the perfection of the coils, and even in the close similarity of peculiar offshoot structures that have been referred to as "rhizome" structures. Elias indicated his general belief that the Daemonelix had been liana-like vegetal forms which had become buried in the Harrison sands. This is much the same suggestion as that made by Riggs[20] some years before.

A liana, according to the *New Standard Dictionary*, is "any one of the various twining or climbing plants of a tropical forest, having usually woody, rope-like stems, and climbing the highest trees or running great distances along the ground." According to the *Encyclopaedia Britannica:*

> Lianes or Lianas, a term applied originally to the climbing plants—often of great size and with massive stems—of tropical forests. Schimper extended the term to include all climbing plants . . . . The term is still, however, mainly used in its restricted sense and applied to tropical climbers. . . . . Climbing plants reach their extreme development in the rain forests of the tropics where the high temperature and the high saturation of the air are eminently suitable for rapid growth. Furthermore, the shade in these forests is very great and climbing on tree trunks is the most economical way of reaching the light above the forest

[20] *Op. cit.*

canopy. It is thus not surprising to find that tropical climbers are very numerous; the number has been estimated at 2,000 or more. Certain botanical families, as Leguminosae, Bignoniaceae, Malpighiaceae, Menispermaceae and Sapindaceae, are peculiarly rich in species which are climbers.

The behavior of tropical climbers is well described by A. R. Wallace in his *Tropical Nature*.[21] "Next to the trees themselves the most conspicuous and remarkable feature of the tropical forests is the profusion of woody creepers and climbers that everywhere meets the eye. They twist around the slender stems, they drop down pendent from the branches, they stretch tightly from tree to tree, they hang looped in huge festoons from bough to bough, they twist in great serpentine coils or lie entangled in masses on the ground. Some are slender, smooth, and root-like; others are rugged or knotted; often they twine in veritable cables; some are flat like ribbons, others are curiously waved and indented..... They pass overhead from tree to tree, they stretch in tight cordage like the rigging of a ship from the top of one tree to the base of another, and the upper regions of the forest often seem full of them..... In the shade of the forest they rarely or never flower, and seldom even produce foliage, but when they have reached the summit of the trees that support them they expand under the genial influence of light and air, and often cover the forest parent with blossoms not its own."

These lianes usually have thick woody stems and as the stems wind round their supports they also twist on their own axes. Associated with this we find that secondary thickening of the wood frequently occurs in an anomalous way. Instead of a single ring of cambium developing a continuous cylinder of secondary wood we have irregular layers of cambium developing irregular masses of wood. The stem may be flattened with bands of wood in the form of arcs of a circle or the stem may be composed of a number of rounded strands of wood. Climbers generally, owing to the narrowness of the cross section of the stem compared with its length, have large and wide wood vessels to facilitate water transport. This reaches its height in the lianes of the tropics, which show in their wood the largest vessels known. *Calamus* (the rattan) and *Desmoncus* among the palms are typical tropical ramblers or scramblers. Their stems are usually thin and reed-like but the leaves possess spines. These spines act like the smaller hooks and hold the stem in position among the surrounding plants. The stem of *Calamus* may reach the enormous length of 600 feet and the plants are a serious bar to progress in a tropical forest.[22]

At another place the *Britannica* (p. 881) in describing the Leguminosae states: "Woody climbers (lianes) are represented by species of *Bauhinia* (Caesalpinioideae), which with their curiously flattened, twisted stems are characteristic features of the tropical

[21] *Tropical Nature* (1st ed., 1878); or *Natural Selection and Tropical Nature* (ed. of 1891 and reprint of 1895 [London and New York: Macmillan Co.]), pp. 246–48.

[22] Vol. XIII (14th ed., 1929), p. 993.

forest, and *Entada scandens* (Mimosoideae) also common in the tropics." It is evident from the above quotations that the lianes or lianas encompass several plant families, many genera, and almost innumerable species, all of which have acquired great similarity of gross structure and habits by adaptation to a common environment.

C. J. Hylander[23] has described and illustrated an unusual North American liana or liana-like tree, the Strangler fig (*Ficus aurea*), which is suggestive of Daemonelix. He states:

> The Strangler fig (*Ficus aurea*), also called the "Golden Fig," is a plant with the peculiar habit of beginning its existence as an epiphyte on some other tree, often on a palm. As the fig grows, it sends down snake-like strangling roots which in time completely encircle the host, and become rooted in the ground; the vine then becomes a real tree. This fig often grows higher than its host; and after the inevitable death of the latter, the giant climber may remain as a spiral growth around a hollow cylinder.

Thus the absence of a fossilized, woody support for some of the Daemonelices would be readily explained were they developed by the Strangler fig or some other tree of the same genus or at least of the same habits. The strangling figs are native to the subtropical tip of Florida, and the writer has found no reasons why they cannot be regarded as true lianas, and such they will be considered in this paper.

The illustrations published by Barbour[24] of internal, microscopic structures, revealing woody tissue, fibers, and tubes and tubules fossilized in the Daemonelix, afford very convincing evidence of the close similarity between the ancient Daemonelix and the modern lianas. Furthermore, it seems to the writer that the term "Daemonelix," instead of representing only a single genus of some supposedly vegetal form, in reality may represent, like the term "liana," a large group of plants containing many genera. The variously shaped and twisted Daemonelix described by Barbour through the widest range of sizes can be perfectly duplicated, it seems, in the lianas of the modern tropical forest or the Strangler fig of Florida. The "twin screw" form of Daemonelix noted by Barbour[25] apparently might

[23] *The World of Plant Life* (New York: Macmillan Co. 1939), pp. 194–97; also C. S. Gager, *General Botany* (Philadelphia: P. Blakiston's Son & Co., 1926), pp. 206–8, 576–78; and Ernst A. Bessey, "The Florida Strangling Figs," *Missouri Bot. Gard. Ann. Rept.*, Vol. XIX (1908), pp. 25–33 and 9 pls.

[24] "History of the Discovery . . . . ," *op. cit.*, and other papers by Barbour.

[25] *Ibid.*, p. 28.

find a counterpart in the modern liana, as would also the "*Daemonelix bispiralis*,"[26] but what rodent would or could make a *bispiralis* burrow or even one to fit the *D. carinata*[27] form? The Daemonelices which are coiled about an axis, as so many are, can hardly be explained by the burrow theory, but this form would be most natural if the Daemonelix was a liana type of plant.

If this be the true explanation of the Daemonelix, it would definitely indicate a tropical or subtropical swamp during late Harrison time throughout the area occupied by these structures. The disappearance of the Daemonelix at the end of Harrison time could be the natural result of a suddenly changed environment. The swamps were drained, less humid and possibly semiarid conditions set in, and erosion began its work. The stratigraphic relations of overlying formations indicate that Harrison sedimentation was followed by valley dissection and extensive drainage development before the next cycle of sedimentation, the Hemingford,[28] began.

HARRISON SEDIMENTATION

Harrison sedimentation is thought to have proceeded much as it had in previous Tertiary cycles. The streams deposited their burdens of sand and silt in the shallow channels and over the wide flood plains, even overtopping the insignificant divides between drainage systems. Much of the water that drained across the plains from the west, as well as the local precipitation, entered the permeable sands, and in general the water table probably stood at the surface or very close to it much or perhaps most of the time. Open ponds and shallow swamps may have been maintained in extensive areas, where the ground surface dropped below the static water table. This is believed to have been the case during the existence of the extensive Daemonelix swamps. If the water table was at a high level, humidity may have been high generally, and mesic conditions probably prevailed over large areas.

The sedimentation conditions indicated above for Harrison time and the cyclical recurrences of humid and dry times throughout the Tertiary period are supported by stratigraphic and sedimentation evidence in the field. The channels of the streams, which accom-

[26] Barbour "On a New Order . . . .," *op. cit.*; see esp. p. 18.

[27] *Ibid.*, p. 20.

[28] Lugn, "Classification of the Tertiary . . . . ," *op. cit.*

plished the aggradation of the Great Plains by depositing the sedimentary wash from the rising Rocky Mountains, are from 10 to 50 and even more feet deep and 100–300 or more feet wide and, furthermore, are filled with materials ranging in texture from coarse gravel to fine silt and clay. Such river channels are comparable to the channels of large modern rivers such as the Mississippi,[29] which carries and handles similar materials on relatively low gradients—for example, 6 inches per mile between Davenport, Iowa, and Cairo, Illinois.

The Tertiary rivers, if we may judge from stratigraphic field evidence, were overloaded permanent streams discharging moderately large volumes of water across the plains on moderate gradients, which the writer suggests ranged from 1 to perhaps 3 feet to the mile. The previously deposited, highly permeable sediment had to be saturated with ground water nearly to the surface throughout the extensive areas of deposition in order to prevent the complete infiltration of the water and to maintain surface flows in the channels and the transportation of debris.

The drier parts of the sedimentary cycles, when the water table receded somewhat and sedimentation was temporarily halted, are generally indicated by well-defined zones of caliche cementation and the subsequent scouring of local channels into these hard zones when a surface flow again was resumed.

Fossil seeds of grasses and herbaceous vegetation of several kinds, which occur in most of the late Tertiary formations of the High Plains, appear to provide reliable evidence on environmental conditions prevailing at the time of deposition of the beds containing the seeds. The fossil seeds of Tertiary times can be closely identified with seeds of modern vegetation; and, in all zones where found, they indicate or suggest nearly the same environmental conditions of deposition as are suggested by stratigraphic and sedimentation data. There is a very high degree of correlation between these three kinds of evidence.

While fossil seeds, except *Celtis*, have so far been found in the Harrison formation only in the uppermost layers above the Daemonelix zone, they are relatively abundant in most of the younger

[29] Lugn, "Sedimentation in the Mississippi River between Davenport, Iowa, and Cairo, Illinois," *Augustana Library Pub., No. XI* (1927).

formations which have quite similar lithology. The close correlation in the Hemingford and Ogallala groups[30] between the evidence of fossil plant ecology and sedimentation and stratigraphy suggests that an interpretation of late Harrison time may safely be based on the available lithologic data. No fossil seeds of grasses or of borages have been found in the Daemonelix beds, suggesting that conditions at that time were not favorable for the grasses and certain other herbs. This fact is further suggestive of the interpretation herein outlined.

It seems likely that drier intervals, shorter perhaps than the more mesic times, alternated with the more humid ages while the upper 100 feet or more—the Daemonelix beds—of the Harrison formation were being deposited. During the long dry spells, probably of many years' duration, the water table presumably receded to moderate depths of perhaps 5–20 or more feet below the surface. Thus the porous sands above the ground water became dry and desiccated. The swamp vegetation died except in the very lowest places. Eolian activity could then increase and dry sand be blown over the landscape to overcome further the swamp and forest vegetation. More humid times followed, the rivers flowed again to bring fresh sediments from the western highlands to complete the burial of earlier "tropical" forests, the ground-water level rose, and new swamps were initiated at new and slightly higher levels.

THE GRAN CHACO

It is not intended to imply that late Harrison conditions were comparable to those in the "tropical rain forests" of today. But sedimentation and climatic conditions in parts of the High Plains of North America during late Harrison time, and perhaps at other ages during the Tertiary period, may have been somewhat similar to the environment in parts of the Gran Chaco region of South America at the present time.

The Gran Chaco is flat and level, built up during comparatively recent geologic ages by accumulation of fluvial sediment from the Andes on the west. The eastward slope of the surface is slight, the rivers are large, sluggish, and choked with debris. They commonly flood very extensive areas during the rainy season. The valleys are

[30] Lugn, "Classification of the Tertiary . . . . ," *op. cit.*

shallow and swampy, with extensive forest cover near the water courses. The divide areas are level, dry to arid in the dry season, and more or less grass covered except where salt pans and swamps make this impossible. Extensive tracts of more or less open woodland are intermingled with grassy plains, and in some places (in Bolivia) large areas of open country are subject to inundation during the rainy seasons. The network of streams from the mountains at the west does not reach far into the lowlands, and during the dry seasons, eolian activity materially assists in the transportation and distribution of alluvial materials.

The water table remains more or less permanently at or near the surface in the swampy areas, such as the *esteros*, *banados*, and *lagunas*, and it inundates those areas and rises many feet generally during the rainy seasons. Near the Andes the rivers are eroding shallow valleys below the general level of the alluvial plain, but farther east they still are aggrading widely. Flood waters convert these areas into great lakes and completely obscure drainage lines. Some extensive depressions are filled with water during flood times but are only baked mud flats in dry periods. Even during the driest times, when it may be 25–30 miles between water holes, the water table may be no more than 20–40 feet below the surface of the ground under the highest interstream or interbasin areas.

The wide range of water-table fluctuation which appears to be characteristic for large areas of the Gran Chaco region is not conducive to the preservation of carbonaceous materials in the sediments or even for the accumulation of humus in the soils. In view of the high porosity and great permeability of the Harrison sands, a similar widely fluctuating water table during that time would have prevented the preservation of humus or carbonaceous materials. Widely ranging local water-table levels during Harrison time probably were under climatic control of a cyclic character involving periods of years, in much the same way as climatic cycles of shorter or longer duration are supposed to influence drought periods at present. The range of water-table fluctuation in Harrison time may have been as great as or greater than it is at present in the Gran Chaco region under seasonal control, but it need not have been larger to have accomplished the results believed to be evident in the Daemonelix beds.

PRESERVATION OF DAEMONELIX

It is believed that conditions like these, with humid epochs alternating with times of desiccation, may have existed during the deposition of at least the upper half of the Harrison formation, which includes the Daemonelix beds. When the water table dropped below the surface and desiccation set in, the soft, pulpy, highly vascular swamp vegetation previously buried would rapidly rot away; but the enclosing sands under these conditions would harden somewhat with the precipitation of more or less of the previously dissolved mineral matter. Under such conditions the soft and rotted liana-like Daemonelix vines or "twisters" would provide ready-made burrows for any rodent to occupy after digging out as much of the decayed corkscrew and rhizome structure as he desired for his accommodation. Thus rodents and other animals as well might have been buried in the Daemonelix burrows. With the return of more humid conditions and sedimentation, sand and silt filtered in to fill the liana-formed Daemonelix home of the humble *Paleocastor*.

The silty sand constituting the Harrison formation, while still unconsolidated and soft enough for a rodent or beaver to burrow into, could hardly have been sufficiently compact and solid to be structurally competent enough to permit an elaborate, closely coiled burrow, such as the Daemonelix, to be excavated without collapsing during the process of digging. However, if the matrix sand had opportunity to become somewhat consolidated around a complexly coiled plant structure, which might after decay be dug out as suggested, the resulting burrow might have remained open indefinitely.

It may be suggested further, since it is the outer shell of the structure or burrow that is preserved and not any large amount of vegetal tissue in any case, that the occupancy of these structures by burrowing creatures may have had much to do with their preservation. After the opening of the burrow, evaporation of moisture would have tended to precipitate mineral matter and harden the wall. Furthermore, the excretions from the animals themselves, as suggested by Peterson,[31] perhaps would have contributed to this same end. Later, secondary cementation has in a majority of cases hardened the filling material until the Daemonelix replacing silty sand is now more resistant than the encircling matrix sand outside

[31] "Description of New Rodents . . . . ," *op. cit.*

of the old outer wall, which explains the "fossilized" condition of these structures.

The explanation for the small remnants and disintegrated condition of fossilized vegetal material becomes apparent when it is realized that most of the wood had rotted away before the rodent found it advantageous to dig out most of the remainder and make his home in the space it had occupied. The modest height of most of the corkscrews found standing probably represents the amount of sedimentation before the Daemonelix had opportunity to disintegrate completely. Presumably countless numbers of these ancient climbers decomposed completely without leaving any vestige to be buried by new floods of sediment.

A partially unanswered question is what became of the tree trunks or stumps which probably supported the liana-like growths, if that is the origin of the Daemonelix. No such supports have endured. The writer has no satisfactory explanation to offer, unless, as already noted, the plants responsible for these structures were in part Strangling figs or trees of similar habits. The Strangling fig (*F. aurea*)[32] is enabled to continue an independent existence long after its supporting host has died and rotted away, leaving the giant climber as a thick spiral growth encoiled around a hollow cylinder. Some of the Daemonelix coils are wide enough to have surrounded some slender supporting structure, and many of them in their present condition appear to be coiled around a definite axis (see Figs. 3 and 4). It may be suggested without apparent possibility of proof that some of these twisters may have had support external to the spiral, in which cases the spirals are closely coiled. Some modern lianas are said to be provided with leaf spines or hooks which "hold the stem in position among the surrounding plants."

Fossilized wood is known from a number of horizons within the Tertiary of Nebraska and from many localities in the state; but fossilized wood, at least to the writer's knowledge, has not been found within the Daemonelix zone. If the woody tissues of the Daemonelix "lianas" were not preserved to any greater degree than they are known to be, it is not likely that other wood could have been better preserved. Furthermore, if the Daemonelix "lianas"

[32] Hylander, *op. cit.*

had a life-history very much like that of the Strangling figs of Florida, the absence of fossilized, woody axial supports for these corkscrews is adequately accounted for.

HARRISON ECOLOGY

The ecological implications for late Harrison time in this paper may seem somewhat revolutionary compared to the highly generalized ecology heretofore accepted. It has quite generally been assumed that this was a time of widespread grassy plains with a fauna of largely grazing animals. In a very broad, general way this may be correct for the Great Plains as a whole, but for the local, more restricted late Harrison environment, xeric conditions quite likely alternated with mesic conditions. During the dry times the grazing animals and the burrowers may have occupied the locale of the Daemonelix; but during the wet intervals, when swamps and bodies of standing water were extensive over the alluvial plain, the Daemonelix environment would have been preferred by browsing animals. While paleontological evidence is not conclusively favorable to this view, it seems not unfavorable to such an interpretation.

It may not be too radical an assumption to believe that some of the animal races of Harrison time, which on the basis of dental and pedal anatomical characteristics stand somewhere between browsers and grazers, perhaps were adaptable to both types of habitat and that these races survived for many generations. However, in general, except along the valleys and channels, the browsing types gradually gave way to the grazing forms.

Careful study of these problems is now under way by several persons interested in correlating the evidence of fossil-seed and animal ecology with sedimentation and stratigraphy, and any further statement of conclusions would be premature at this time. However, it is now evident that most reported faunas not only from the Harrison formation but from nearly all Great Plains Tertiary formations and zones are unfortunately mixed and generalized, too little care having been exercised by collectors in the field to differentiate and segregate geographically and stratigraphically the groupings of grazing animals from local faunas of browsers or semi-browsers, which lived for the most part in the valleys and in local mesic areas. That these two kinds of environments with different animal assemblages existed contemporaneously and close together can no longer be doubted.

CLIMATIC IMPLICATIONS

More complete reports on Tertiary environments in Nebraska and adjoining areas are in preparation by Elias and the writer[33] and by others. A brief statement of the climatic implications for the High Plains Tertiary (Oligocene to Pliocene) based on detailed studies of the sedimentation, fossil seeds, and animal faunas by M. K. Elias, C. B. Schultz, T. M. Stout, and the writer during the last ten or twelve years will be included here for their bearing on the problem in hand. They must, however, be considered highly tentative and subject to modification.

Oligocene climate (White River) appears to have been warm and, except in the major valleys, dry at first, more humid at the close of Chadron time, and then dry to more or less arid during much of Brule time, but with intervals of greater humidity (the "nodular" zones) and in general a high water table but dry atmosphere.

Arikaree time (Miocene-Gering, Monroe Creek, and Harrison formations) began dry, except in the major valleys, appears to have become more humid with a relatively high water table during the Monroe Creek and Harrison ages, to at least locally mesic with extensive swamps in late Harrison time (the Daemonelix beds). The Gering valley plains were mesic, but the contemporary interstream areas may have been dry to actually arid. It is thought that the atmosphere may have been very dry during much or even most of Monroe Creek and early Harrison times, which with a high water table resulted in caliche development on an extensive scale.

This seemingly anomalous condition was possible because the water which filled the sediments to a high level, as already explained, had drained from the well-watered, mountainous region to the west, and it was more or less widely dissipated from the channels of the

[33] M. K. Elias and A. L. Lugn, "Late Tertiary Environment in a Portion of the High Plains, *Bull. Geol. Soc. Amer.*, Vol. L (1939), pp. 1907–8; M. K. Elias, "Trend of Changes in the Late Tertiary Prairie," *Bull. Geol. Soc. Amer.*, Vol. LI (1940), p. 1925; and A. L. Lugn, "Tertiary and Pleistocene Sedimentation in Relation to the Pliocene-Pleistocene Boundary in the Great Plains," *Bull. Geol. Soc. Amer.*, Vol. LI (1940), pp. 1934–35.

aggrading streams to ground storage in the permeable sands and silts of the earlier deposits over the plains. Semiarid to arid atmospheric conditions could have prevailed, and probably did prevail, over the plains east of the mountains then as now.

The temperature during Arikaree and Hemingford time (Miocene) may have begun warm or even tropical and have become subtropical or at least cooler toward the end of the epoch. Hemingford time (Marsland and Sheep Creek formations) appears to have been relatively dry at the beginning and more mesic at the end, in most particulars similar to the earlier and longer Monroe Creek–Harrison interval.

The Pliocene epoch (Ogallala group) appears to have had moderate temperatures, becoming colder toward the end. It began dry, except along the main valleys, became more mesic with a widespread, shallow water table (caliche zones), and at the end was very mesic and humid with widespread ponds and lakes in which fresh-water algal limestone was formed (Kimball formation), throughout the High Plains from Nebraska to Texas.

CONCLUSIONS

The fluviatile environment believed to have existed during the deposition of the upper part of the Harrison formation and the development of the Daemonelices has been described in some detail. A close correlation exists between the three kinds of evidence supplied by stratigraphy, sedimentation, and the ecology of fossil grasses and herbs (fossil seeds) in evaluating the environment of Harrison time, as well as for other Tertiary ages.

It is thought that the interpretation of the environment of late Harrison time outlined in this paper may help to account for the origin of the Daemonelix structures, that it demonstrates the possible vegetal nature of these strange fossils, provides an adequate explanation for the rodent skeletons present in many of them, and to some extent harmonizes the two principal theories of their origin.

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